Air Combat Training Systems

These systems employ both fixed and aeronautical mobile components and are discussed under the mobile service in the air combat training systems.

Fixed Tropospheric Scatter

Most fixed systems operate in a line-of-sight mode of operation, that is, with no obstructions between the transmitter and receiver. Tropospheric scatter communication relies on the fact that a small amount of radio waves under certain conditions is scattered from irregularities in the troposphere as illustrated in Figure 3-3. With sufficient transmitter power and 800 km highly sensitive receivers, reliable communications can be obtained over distances better than 300 km[13]. TABLE 3-5 (previous page) describes the tropospheric scatter communication links which are used for emergency communications, in the 1710-1850 MHz band.

MOBILE SERVICES

The Federal Government, primarily the military services, operates a variety of mobile systems in the band to support combat training, and research and development activities. The predominate use of the mobile service is at military bases and the various National Test and Missile Ranges. Much of the spectrum use at the test ranges are locally scheduled and coordinated. Figure 3-4 shows the location of these test ranges and the area of cognizance for the local frequency coordinators. In addition, emergency response and public safety organizations operate and conduct large scale exercises to prepare for and respond to a wide variety of emergencies and disasters, such as hurricanes, earthquakes, chemical and nuclear power plant accidents.

Air Combat Training Systems

These systems are used by the military at more than 17 sites across the United States to provide realistic tactical simulation and pilot training in a peacetime environment. Training is provided in air warfare operations and maneuvers without actually firing the weapons. The systems provide real-time altitude, location, velocity, angle of attack, simulated weapon status and other data on up to 36 participating aircraft. The system has gone through a series of upgrades and name changes, including the Air Combat Maneuvering Instrumentation, Air Space Position Measuring System, Air Combat Maneuvering Range and Tactical Aircrew Combat Training System. A typical configuration for a system, shown in Figure 3-5, consists of a master control station, six or seven remote tracking stations and up to 24 participating aircraft. The geographical area of coverage is up to 65 km and may remain in operation for up to 10 hours per day. Altitudes of up to 15000 feet are typical during exercises. Recent system upgrades provide for multiple control stations and up to 36 aircraft. These are tied

---

[13] Mellen, G.L., et al., "UHF Long-Range Communication Systems," Proceedings of the IRE Conference on Scatter Propagation Issue, 1955, pp. 1269-1280.

together via radio links, nine or ten of which are required for each system. A number of ACMI sites are being planned at classified locations throughout the United States.

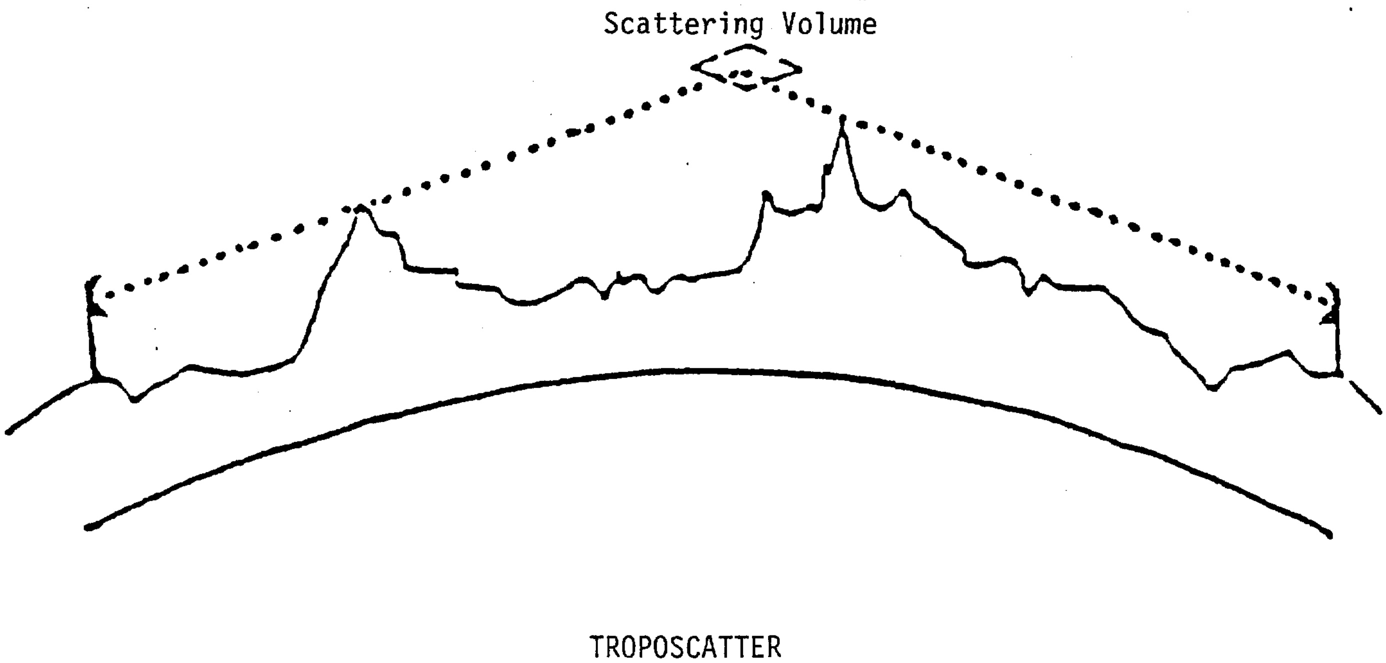

Figure 3-3. Tropospheric scatter communications relies on scattering from the troposphere.

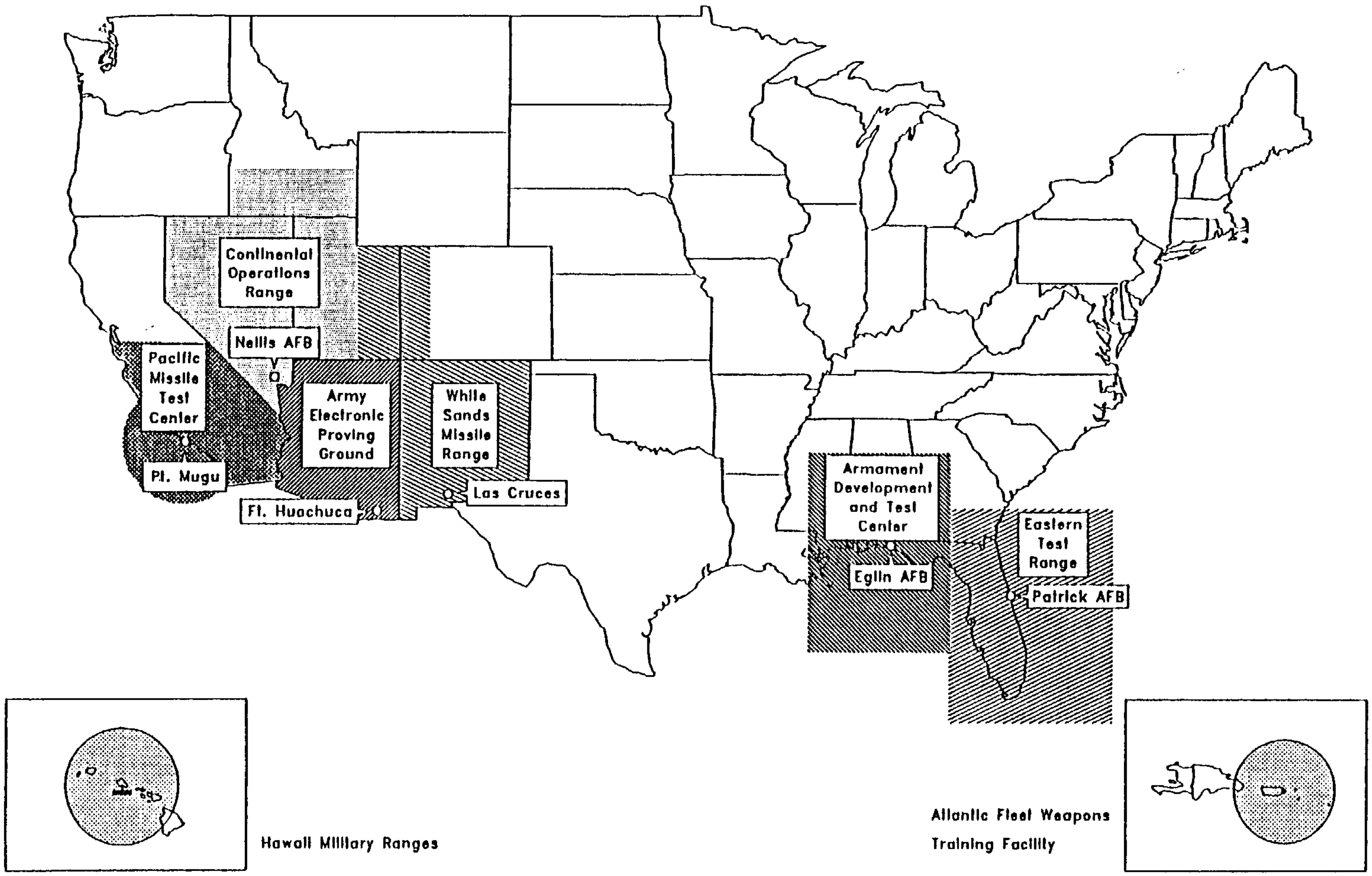

Figure 3-4. National military test range and geographical areas of cognizance.

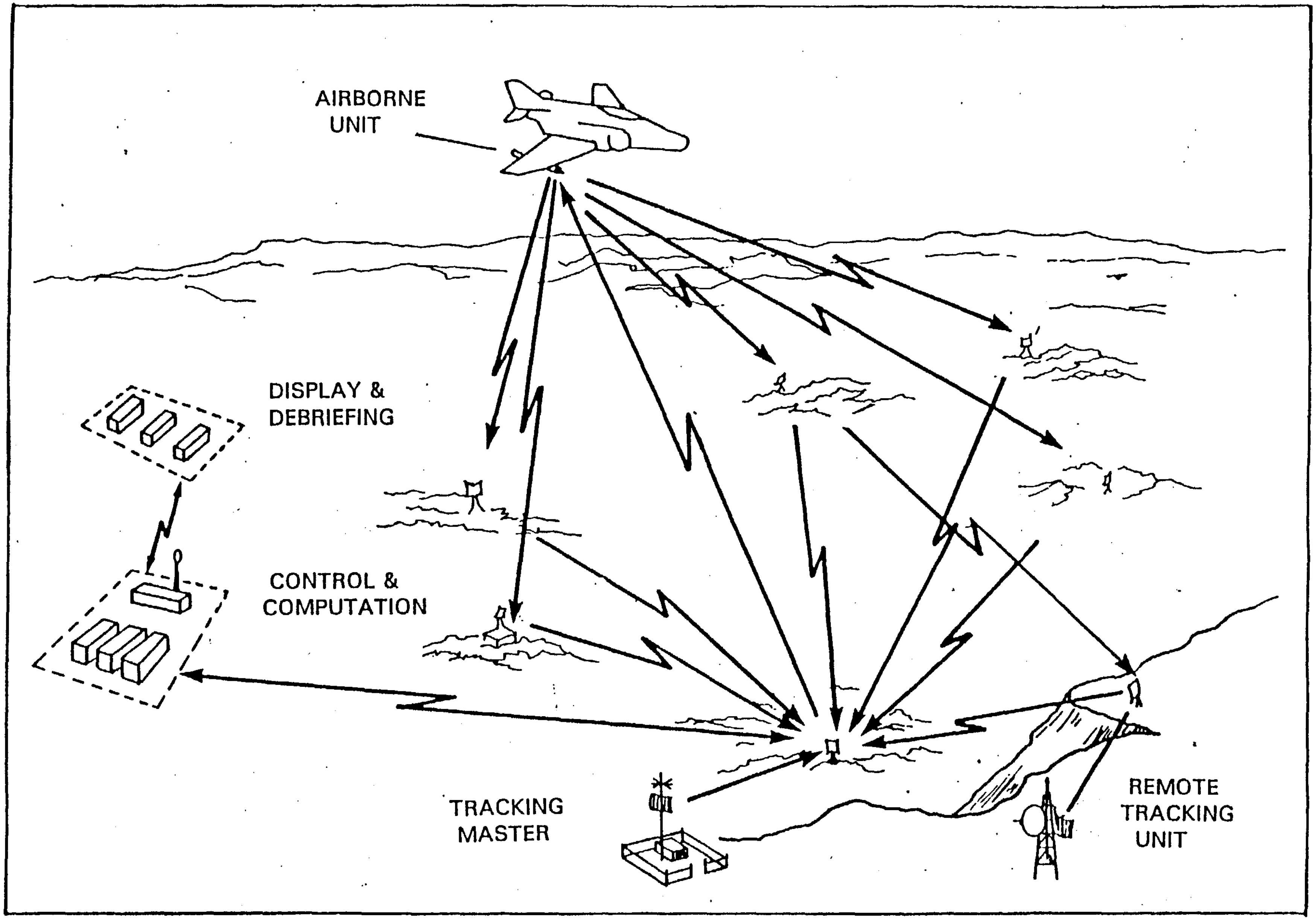

Figure 3-5. A typical configuration for an Air Combat Training System.

Air/Ground Video Systems

The air/ground video systems include many interactive video links and the video telemetry downlinks. The aircraft, typically flying at 10,000 to 15,000 feet, provide a variety of operations such as video images of missile testing, visual radar telemetry and video surveillance for the range commanders. The 65 assignments for air/ground video systems represent a much larger number of transmitters in the inventory. Over 50% of these systems use some form of video compression (3 MHz bandwidth), with the majority having a peak power of 5 watts. Conventional video links require up to 25 MHz of bandwidth.

Weapon and Target Scoring Systems

The DOD operates a variety of radio-based target scoring systems for training and weapons testing purposes. Due to the classified nature of some of these systems, it is not possible to describe them except in very broad terms. Because of the need to maintain a high level of combat readiness, these systems are tested on a regular basis. Currently, these airborne training activities are undertaken primarily within the geographic areas defined by the seven recognized National Test Ranges shown on Figure 3-4. In recent years, the target scoring systems have become quite complex and provide multiple functions such as, indicating whether a target was hit, how much of the target was destroyed, projectile velocity and target tracking.

Miscellaneous Mobile Systems

Included in the band are a variety of additional aeronautical and land mobile systems to relay video, telemetry and telecommand data for applications such as tethered radar balloons, robotic control and sonobuoy telemetry. The systems are used at a variety of locations nationwide.

SPACE SERVICES

The Air Force operates a worldwide system called the Air Force Satellite Control Network (AFSCN) that provides tracking, telemetry and control for Department of Defense orbiting satellites. Over 85 satellites, both geostationary and non-geostationary, and certain Space Shuttle functions, are controlled from the primary tracking stations at Vandenberg AFB, CA; New Boston, NH; Anderson AFB, Guam; Kaena Pt., HI; and Falcon, CO; in addition to overseas sites. Other limited use AFSCN sites include Fairchild, WA; Buckley Field, CO; Loring, ME; Cape Canaveral AFB, FL; and Boulder, CO. The transmitters provide command uplinks in the band 1761-1842 MHz with the telemetry downlinks in the 2200-2290 MHz band. Command tracking is accomplished by using ground station antennas combined with phase comparison techniques between the uplink signal and the return signal from the satellite-borne transponders. The uplink signal is transmitted with a E.I.R.P. of 86 dBW (10kW power and 46 dBi antenna gain) and emission bandwidth of 4 MHz. Assignments for

20 channels separated by 4 MHz[14] at each AFSCN stations have been authorized, which may limit other users in the 1761-1842 MHz around those AFSCN sites. These tracking facilities have large coordination contours around each AFSCN location.

The DOD also has compatible transportable satellite control stations that provide additional coverage for launch and on-orbit operations. These transportable earth stations are used, for example, when fixed sites cannot provide required mission coverage.

RADIO ASTRONOMY

The International Telecommunication Union (ITU) defines *Radio Astronomy* as astronomy based on the reception of radio waves of cosmic origin. Modern radio astronomy receivers are up to 6 to 12 orders of magnitude more sensitive than receivers commonly encountered in the communications services. The 1-3 GHz part of the spectrum is of interest to the radio astronomer since it contains the 1420 MHz hydrogen line and the four lines of the hydroxyl radical (OH) at 1612, 1665, 1667 and 1720 MHz. This spectral region is of prime importance for observing pulsars, quasars and radio galaxies.

Although radio astronomy observations in the 1718.8-1722.2 MHz band do not receive primary allocation status, international agreements urge administrations to take all practicable steps to protect this service from harmful interference. In the United States, observations in the 1718.8-1722.2 MHz band are carried out at the following locations:

1. National Astronomy and Ionosphere Center Arecibo, Puerto Rico	Rectangle between latitudes 17°30'N and 19°00'N and between longitudes 65°10'W and 68°00' W.
2. Haystack Radio Observatory Tyngsboro, Massachusetts	Rectangle between latitudes 41°00'N and 43°00'N and between longitudes 71°00'W and 73°00'W.
3. National Radio Astronomy Observatory Green Bank, West Virginia	Rectangle between latitudes 37°00'N and 39°15'N and between longitudes 78°30'W and 80°30'W.
4. National Radio Astronomy Observatory Socorro, New Mexico	Rectangle between latitudes 32°30'N and 35°30'N and between longitudes 106°00'W and 109°00'W.

[14] Cerezo, Ernesto A., page 5-11.

5. Owens Valley Radio Observatory Big Pine, California	Two contiguous rectangles, one between latitudes 36°00′N and 37°00′N and between longitudes 117°40′W and 118°30′W and the second between latitudes 37°00′N and 38°00′N and longitudes 118°00′W and 118°50′W.
6. Hat Creek Observatory Hat Creek, California	Rectangle between latitudes 40°00′N and 42°00′N and between longitudes 120°15′W and 122°15′W.

SECTION 4
ANALYSIS

INTRODUCTION

The primary focus of this study is to investigate whether 2 GHz non-government fixed microwave systems could be accommodated in the 1710-1850 MHz Federal Government band. The issues can be formulated into three questions:

1. Can all or most of the 2 GHz non-government fixed systems be relocated into the 1710-1850 MHz band?

2. Can a limited number of 2 GHz non-government fixed systems, such as those that may not operate reliably in higher frequency bands, be relocated into the 1710-1850 MHz band?

3. If some of the 2 GHz non-government fixed systems can be accommodated in the 1710-1850 MHz band, what guidelines could be used to identify candidate systems?

This section of the report will address these questions from several perspectives in order to develop data that can be used to formulate answers.

RELOCATION ANALYSIS

Regarding the first two questions, the ability of the 1710-1850 MHz band to accommodate the non-government fixed systems, several approaches are possible. One approach would involve a case-by-case analysis of each of the nearly 30,000 non-government fixed microwave links, using standard interference criteria to specifically identify which ones could, or could not, be accommodated. This approach was not found practical to provide generalized conclusions in a timely manner. Instead, the approach followed was to use statistical/graphical methods to show estimates of spectrum usage, spectrum availability and/or band capacity. These results, in turn, can be used in broad terms to assess the capability of relocating the fixed systems into the 1710-1850 MHz band. Two methods, developed by the FCC and NTIA, respectively, were reviewed and applied to this issue.

FCC Method

The FCC describes one useful statistical/graphical method[15]. In this method, the geographic distribution of the transmitters in a band is characterized by dividing the United States into one-degree-by-one-degree blocks (i.e., one degree in latitude and one degree in longitude) and counting the number of transmitters in each block. Graphical and statistical results are then derived from this data.

---

[15] Marrangoni, Paul, et al, pages 12-28.

Using this approach, the FCC study provided the results for the 2 GHz non-government bands, which is reproduced in Figure 4-1. The FCC study also developed similar distributions for three candidate relocation bands at 4, 6 and 6.7 GHz. The feasibility of relocating fixed microwave systems from the 2 GHz bands to these candidate bands was determined by comparing the number of facilities in each one degree block at 2 GHz with the capacity to accommodate these facilities in the candidate band within that same one degree block.

From the data available, the FCC study estimated an achievable capacity per one degree block, or benchmark, for each target band. The FCC benchmark selection for each band was based on the highest number of transmitters in any one block nationwide. The actual benchmark values used in the FCC study were rounded-off to somewhat lower than the maximum value. The assumption was that if that number of transmitters can be successfully operated without interference in one block then that same number should be achievable in all blocks.

The benchmarks chosen in the FCC study were 400 transmitters per one degree block in the 4 and 6 GHz common carrier bands and 250 transmitters for the 6.7 GHz private band. By comparing the number of existing facilities in each block with the benchmark capacity, the FCC study concluded that the three higher bands could accommodate all of the nearly 30,000 fixed systems operating at 2 GHz.

While the one degree block analysis provides a useful national perspective, the FCC study points out that it does not clearly demonstrate the capacity to relocate in the dense concentrations in major metropolitan areas. The greatest pressure to relocate the incumbent users will occur in the metropolitan areas because of the concentrated demand for new mobile services. To take this factor into account, the FCC study further examined available capacity in various metropolitan areas. A similar analysis approach was used except that two-degree-by-two-degree blocks were defined around each of the top 50 Metropolitan Statistical Areas (MSAs). Because of the larger areas, larger benchmarks were also used. Again, the benchmark for each band was based on the highest number of transmitters in any one of the 50 MSAs (and similarly rounded-off to somewhat lower values). The FCC study chose benchmark capacities of 1100 transmitters per MSA for the 4 and 6 GHz band and 500 transmitters for the 6.7 GHz band. The FCC study concluded that all of the 2 GHz microwave systems within the defined areas around the MSAs could be accommodated in the three higher bands.

These findings by the FCC were borne out by a detailed study[16] undertaken by Comsearch Inc. The study explored alternative bands for fixed systems operating in the 1850-1990 MHz band, through use of a frequency coordination case study of the Houston, Texas area. Using detailed link-by-link analysis, the study found that 96% of the existing links in the 1850-1990 MHz band could be successfully relocated to the 6540-6870 MHz band.

---

[16] Comments before the Federal Communications Commission in the Matter of Redevelopment of Spectrum to Encourage Innovation in the Use of New Telecommunications technologies, ET Docket No. 92-9, Comsearch Inc.

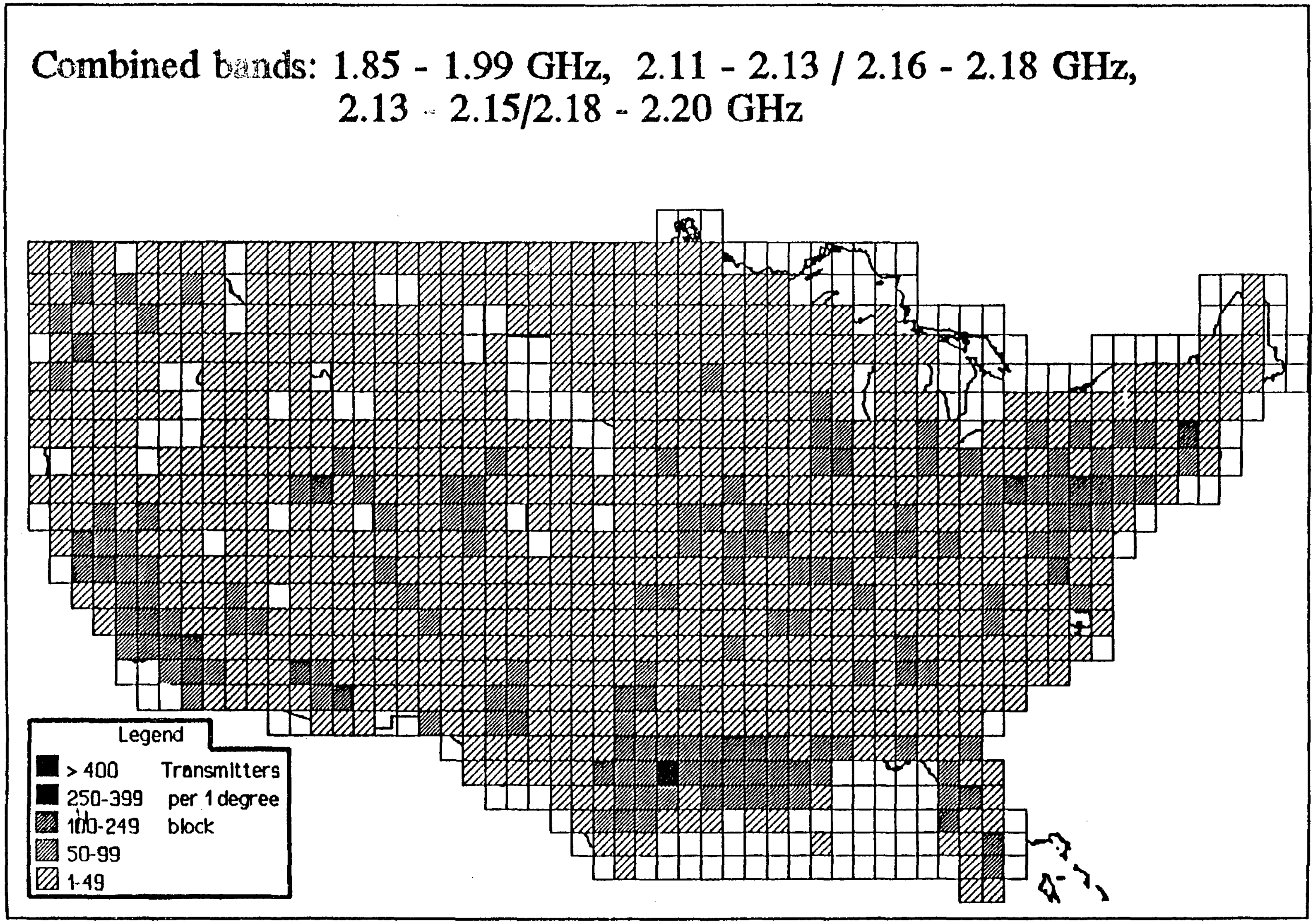

Figure 4-1. Distribution of 2 GHz non-government microwave systems.

The key to the feasibility of relocating non-government fixed systems into the 1710-1850 MHz band is its availability in the metropolitan areas. Following the approach used by the FCC, the availability of spectrum in the 1710-1850 MHz band was examined for the top 50 Metropolitan Statistical Areas. The results, shown in TABLE 4-1, provide a general indication of the ability to accommodate 2 GHz non-government fixed systems that cannot be relocated to higher frequency bands.

There is, however, a limitation to this approach in analyzing the available capacity in the 1710-1850 MHz band. While this approach provides a useful overview of band capacity and relocation issues when the types of applications in each band are consistent, e.g., only fixed microwave systems (the situation in the 2 GHz non-government band), it is less valid for comparing the available capacity in bands that contain systems with vastly different characteristics (the situation in the 1710-1850 MHz band). For example, using this approach, systems having a bandwidth of 1 MHz are given the same weight as those having a 30 MHz bandwidth. Similarly, an aeronautical mobile transmitter at 15,000 feet altitude, with an omnidirectional antenna, is given the same weight as a highly directional fixed microwave transmitter on the ground. Also, a 10,000 Watt satellite control transmitter is measured the same as a 1 Watt fixed transmitter.

Considering the different uses in the 1710-1850 MHz band, its capacity will necessarily be smaller than the 2 GHz non-government spectrum, which is used only for fixed services. Through use of highly directional antennas and terrain shielding between sites, several different fixed microwave systems can operate on the same frequency in relative close proximity without interference in the 2 GHz band. The assignment data from TABLE 4-1 confirms that, in many areas, frequencies are re-used many times within a two-degree-by-two-degree area. For example, it is seen that in the Los Angeles area 660 assignments are accommodated in a bandwidth of 220 MHz.

However, when frequency bands are used to support fixed, mobile, and space services, such as in the 1710-1850 MHz band, the degree of re-use that is possible is substantially reduced. A typical aeronautical mobile system in this band has a 10 Watt transmitter, omnidirectional antenna, and 6 MHz bandwidth. The typical operating altitude is 15,000 feet and average operational radius around the cooperating ground station is 95 km (59 mi.). Under these conditions, the potential interference range to a fixed microwave system can extend as far as the radio horizon. The radio horizon for an altitude of 15,000 feet is approximately 280 km (174 mi.). This precludes a frequency used by an aeronautical mobile system in a metropolitan area from being re-used by any other service.

High powered satellite control transmitters operating in the 1710-1850 MHz band further reduce available band capacity. Because these systems employ transmitter powers up to 10,000 Watts and have high gain antennas, capable of pointing at any azimuth at low elevation angles, fixed systems located within a very large distance of these satellite control transmitters must be coordinated to assure interference-free service[17].

---

[17] Cereso, Ernesto A., Page 3-3

TABLE 4-1
TOP 50 METROPOLITAN STATISTICAL AREAS (Per 1990 Census)

RANK	LOCATION	BENCHMARK CAPACITY	2 GHz ASSIGNMENTS	1710-1850 MHz ASSIGNMENTS	CAPACITY FACTOR	
1	New York, NY (CMSA)	180	263	85	-168	
2	Los Angeles, CA (CMSA)	180	660	188	-668	
3	Chicago, IL (CMSA)	180	320	20	-160	
4	San Francisco, CA (CMSA)	180	543	170	-533	
5	Philadelphia, PA (CMSA)	180	314	49	-183	
6	Detroit, MI (CMSA)	180	173	13	-6	*
7	Boston MA (CMSA)	180	255	81	-156	
8	Washington, DC (MSA)	180	327	70	-217	
9	Dallas-Fort Worth, TX (CMSA)	180	373	76	-269	
10	Houston, TX (CMSA)	180	581	33	-434	
11	Miami-Ft. Lauderdale, FL (CMSA)	180	300	24	-144	
12	Atlanta, GA (MSA)	180	325	55	-200	
13	Cleveland, OH (CMSA)	180	144	19	17	*
14	Seattle-Tacoma, WA (CMSA)	180	276	108	-204	*
15	San Diego, CA (MSA)	180	165	35	-20	
16	Minneapolis-St. Paul, MN (CMSA)	180	174	1	5	
17	St. Louis, MO (MSA)	180	182	26	-28	
18	Baltimore, MD (MSA)	180	386	62	-268	
19	Pittsburgh-Beaver Valley, PA (CMSA)	180	264	16	-100	
20	Phoenix, AZ (MSA)	180	238	85	-143	
21	Tampa-St. Petersburg-Clearwater, FL (MSA)	180	241	9	-70	
22	Denver-Boulder, CO (CMSA)	180	318	97	-235	
23	Cincinnati, OH (CMSA)	180	175	4	1	
24	Milwaukee-Racine, WI (CMSA)	180	196	4	-20	
25	Kansas City (MO-KS), MO (MSA)	180	229	57	-106	

KEY

Benchmark Capacity: An estimated number of transmitters that could be accommodated without mutual interference in the 1710-1850 MHz band within a two-degree-by-two-degree block around each of the MSAs. The value chosen is based on the highest number (rounded-off) of transmitters currently operating in the 1710-1850 MHz band in any of the MSAs. The indicated benchmark capacity is useful as a relative measure but cannot be taken as an absolute measure of the total number of assignments that can be accommodated into the band.

2 GHz Assignments: The number of non-government fixed assignments in the 2 GHz fixed band. This is approximately equal to the number of transmitters in the band.

1710-1850 MHz Assignments: The number of Federal Government assignments, including fixed, mobile and Earth stations, in the 1710-1850 MHz band. The number of transmitters may exceed this number, since one assignment may represent multiple transmitters for mobile and transportable systems.

Capacity Factor: The estimated capacity that would remain in the 1710-1850 MHz band in each of the MSAs if both the current Federal Government and non-Government transmitters were accommodated in the band. For example, for New York City, the benchmark capacity (180) minus the non-government and Federal systems (263 and 85, respectively) yields a capacity factor of -168. A positive number indicates that all could be successfully accommodated with additional capacity still remaining. A negative value indicates that the capacity would be inadequate to accommodate all transmitters by the amount indicated.

* Spectrum usage by Canada near these areas significantly reduces the available capacity.

TABLE 4-1 (Continued)
TOP 50 METROPOLITAN STATISTICAL AREAS (Per 1990 Census)

RANK	LOCATION	BENCHMARK CAPACITY	2 GHz ASSIGNMENTS	1710-1850 MHz ASSIGNMENTS	CAPACITY FACTOR
26	Sacramento, CA (MSA)	180	531	109	-460
27	Portland-Vancouver, OR (CMSA)	180	195	42	-57
28	Norfolk-Virginia Beach-Newport News, VA (CMSA)	180	154	15	11
29	Columbus, OH (MSA)	180	42	3	135
30	San Antonio, TX (MSA)	180	358	82	-260
31	Indianapolis, IN (MSA)	180	105	36	39
32	New Orleans, LA (MSA)	180	471	38	-329
33	Buffalo-Niagra Falls, NY (CMSA)	180	113	7	60 *
34	Charlotte-Gastonia-Rock Hill, NC (CMSA)	180	208	5	-33
35	Providence-Pawtuckett-Fall River, RI (CMSA)	180	237	42	-99
36	Hartford-New Britain-Middletown, CT (CMSA)	180	218	30	-68
37	Orlando, FL (MSA)	180	290	16	-126
38	Salt Lake City-Ogden, UT (CMSA)	180	252	69	-141
39	Rochester, NY (MSA)	180	94	5	81 *
40	Nashville-Davidson, TN (MSA)	180	148	34	-2
41	Memphis, TN (CMSA)	180	224	41	-85
42	Oklahoma City, OK (MSA)	180	103	44	33
43	Louisville, KY (MSA)	180	152	52	-24
44	Dayton-Springfield, OH (MSA)	180	129	4	47
45	Greensboro-Winston Salem-High Point, NC (MSA)	180	214	30	-64
46	Biringham, AL (MSA)	180	173	13	-6
47	Jacksonville, FL (MSA)	180	180	23	-23
48	Albany-Schenectady-Troy, NY (MSA)	180	198	2	-20
49	Richmond-Petersburg, VA (MSA)	180	242	25	-87
50	West Palm Beach-Boca Raton-Delray, FL (MSA)	180	296	16	-132

Other factors that further reduce the capacity of the 1710-1850 MHz band as compared with the 2 GHz non-government band are the total available bandwidth and the average bandwidth of each system. The 2 GHz non-government bands included on TABLE 4-1 have a total available bandwidth of 220 MHz and the average bandwidth of each system operating in the band is approximately 3.5 MHz. Conversely, the 1710-1850 MHz band is only 140 MHz wide and contains systems that have bandwidths up to 25 MHz. It is to be noted that operation of such systems will preclude the accommodation of more fixed services than if the band were occupied by only small bandwidth services.

However, even with these noted limitations and qualifications, this analysis method provides a useful general overview of band availability. The analysis indicates that, while the 1710-1850 MHz band cannot accommodate all, or even most, of the 2 GHz non-government links, it is feasible to accommodate a limited number in most of the major metropolitan areas. For the reasons given above, the benchmark capacity, indicated on TABLE 4-1, is useful as a relative measure but cannot be taken as an absolute total number of assignments that can be accommodated into the band. The ability to reaccommodate a specific link or system can only be determined through a case-by-case analysis considering the operating environment, geographic location and frequencies currently in use. It must be noted that certain classified operations of the Federal Government have not been included in the tabulated data in TABLE 4-1. Such uses will be taken into account in appropriate case-by-case analysis.

Spectrum Use Measure (SUM)

A method developed by NTIA, the Spectrum Use Measure (SUM) model,[18] considers transmitter power, bandwidth, antenna, and altitude to evaluate spectrum use. This model can be used to graphically portray the spectrum use in a frequency band for a defined geographic area. The specific model option of interest to this study will display the available clear spectrum on a national basis. The model uses a frequency assignment data base and a reference system described by the user as the basic input information. It is presently configured to use the Government Master File of frequency assignments. The model works by hypothetically placing the reference system at a series of test locations. At each of these test locations, interference levels both to and from the reference system are computed and the amount of available spectrum available at that point is determined and stored for later display. Standardized equipment characteristics and interference criteria are used in these calculations. The test points are placed in a grid to cover the geographic area of interest, in this case the United States. The grid spacing is user defined and was chosen to be 8 km (5 miles) for this study, resulting in over 200,000 test point calculations. Geographic contours of the available spectrum can then be computed and displayed. Appendix C provides further description of the SUM model and assumptions used for this study.

A key advantage of the SUM Model, as it applies to this study, is that key technical parameters such as transmitter bandwidths, transmitter power and high altitude factors are

[18] Mayher, Robert J., et.al., *The SUM Data Base: A New Measure of Spectrum Use*, NTIA Report 88-236, National Telecommunications and Information Administration, August 1988.

effectively considered. A 30 MHz bandwidth system, all things being equal, will result in up to 30 times the spectrum impact of a 1 MHz bandwidth system. Similarly, the impact of an aeronautical transmitter at 15,000 feet altitude will be up to 10 times as great as a conventional fixed microwave system on the ground.

Figure 4-2 illustrates the results obtained from the SUM model for the 1710-1850 MHz band. The results show a large variation in spectrum available in various geographic areas. The area where least spectrum is available is on the West Coast and on military test and missile ranges in the Southwestern United States. The extensive airborne applications in these regions result in much larger spectrum use than a like number of fixed microwave systems. Numerous smaller congested areas appear throughout the Eastern half of the United States. Data for Hawaii and Alaska were not included because of time limitations.

Relocation Summary

The two analysis methods discussed here provide a broad overview of spectrum availability in the 1710-1850 MHz band and several conclusions are clear:

* The study found that due to the present use of the 1710-1850 MHz band and the need to maintain flexible, continued use by Federal agencies, this band could not accommodate all or even most of the existing 2 GHz private-sector fixed microwave links.

* In most parts of the United States, it is feasible to accommodate a limited number of 2 GHz non-government fixed links into the 1710-1850 MHz band. As shown in TABLE 4-1, in most of the 50 top metropolitan statistical areas, capacity is available in the 1710-1850 MHz band to support a limited number of additional fixed links. Figure 4-2 provides a national overview of spectrum availability in the 1710-1850 MHz band.

* In certain areas of the country, especially California and the Southwestern United States, the available spectrum is quite limited and few 2 GHz non-government fixed systems can be expected to be accommodated in these areas. Additional pockets of especially high use are distributed throughout the country.

* In regions near the United States-Canada border, available spectrum in the 1710-1850 MHz band is limited because of large usage of these bands in Canada.

The analysis undertaken here is an important first step in determining the availability of spectrum in the 1710-1850 MHz band. If non-government systems are accommodated in the band, more detailed interference analysis must ultimately be used on a case-by-case basis to determine compatibility of each relocated link. The degree of accommodation for each case is a function of many factors, including characteristics of the existing and relocated systems, terrain, and climate.

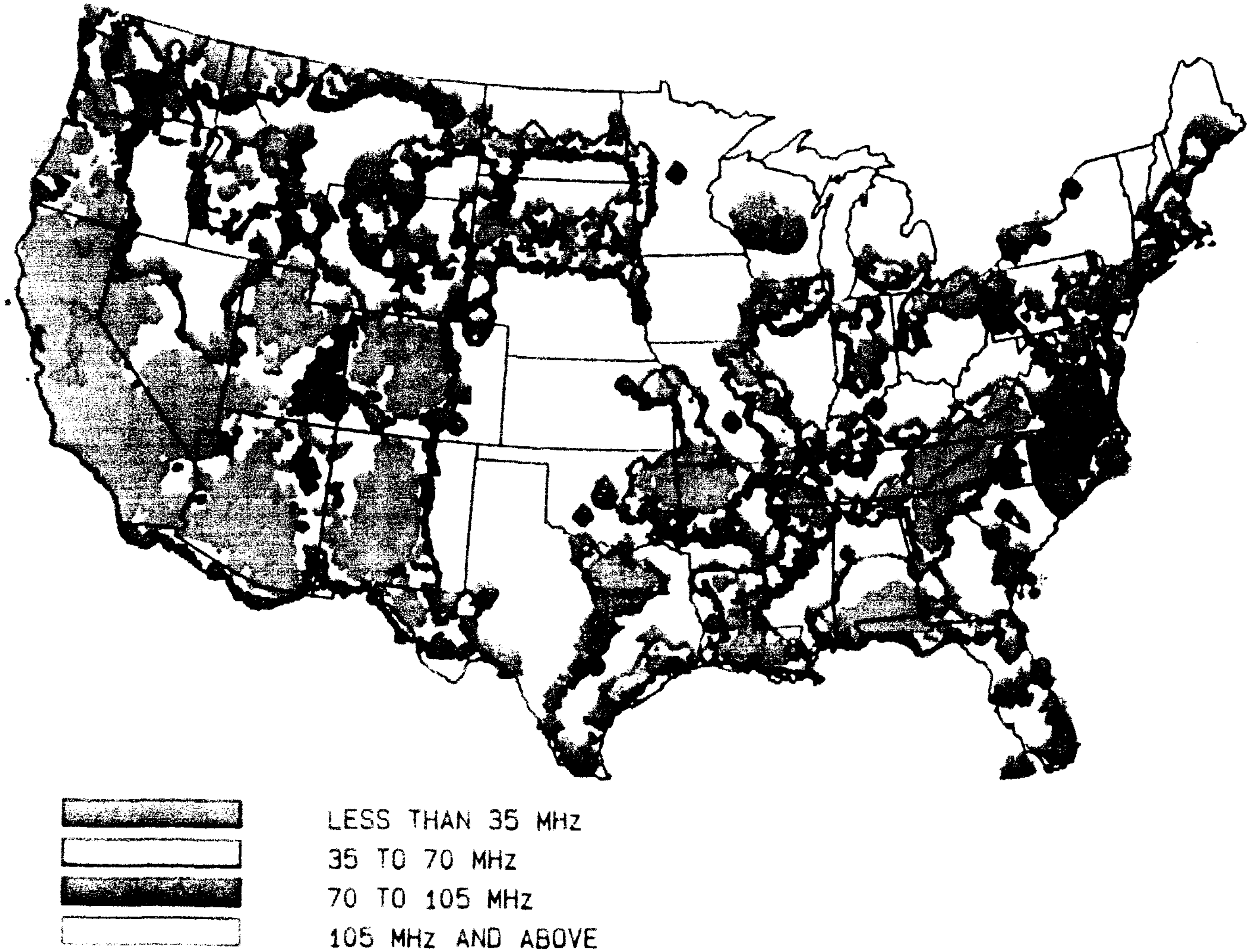

Figure 4-2. SUM map of spectrum bandwidth available in the 1710-1850 MHz band.

RELIABILITY

If a limited number of 2 GHz non-government fixed links can be relocated to the Federal 1710-1850 MHz band, the question remains as to which ones are appropriate candidates. The issue of reliability is central to this question. Reliability is generally defined as the percentage of time the communications system is functioning properly. Many opposing views have been expressed on the subject of reliability. Some of the incumbent 2 GHz fixed users have expressed concern over the ability of their systems to continue to operate reliably if they were relocated to higher frequencies such as 6 GHz. Others have stated that, with proper engineering, including use of space diversity techniques when necessary, most current paths at 2 GHz could be relocated with high reliability to 6 GHz and other upper bands.

Appendix D further explores the issues of reliability. The data provided in the Appendix supports the view that, for most locations, reliable microwave operation can be achieved at higher frequencies. However, the intention here is not to attempt to resolve all aspects of this complex issue; the following discussion will focus on the areas where there is general agreement among microwave design experts and users. From these areas of agreement, a suitable, overall relocation strategy can be developed.

Microwave Reliability Requirements[19]

Microwave system reliability is primarily a function of radio propagation conditions. A system is said to have a reliability of 99.99% if communications are disrupted less than 0.01 percent of the time during the year. This is equivalent to 53 minutes or less of disrupted communications in a one year period. Some systems are designed for a reliability (for each hop) as high as 99.9999% which is equivalent to 32 seconds per year of disrupted communications. Microwave systems must be designed to overcome changes in propagation, commonly referred to as "fades." Each link in the microwave system is designed to have extra signal strength, or fade margin, to overcome the effects of fading.

In general, signal fades may be due to factors such as rain attenuation, reflections from water and atmospheric effects such as atmospheric multipath and ducting. Path length and frequency play a role in the severity of these conditions. These factors must be taken into consideration in designing a microwave system and are briefly discussed below.

Rain Attenuation

Attenuation of the microwave signal due to rain is a factor that must be taken into account in microwave system design. However, the effect is so small as to be insignificant, in comparison to other types of fading, for the bands below 10 GHz. This view is confirmed

[19] Discussion is extracted from Marrangoni, Paul, et al, which in turn referenced: Keiser, Bernhard E., Broadband Coding, Modulation, and Transmission Engineering, Prentice Hall, Englewood Cliffs, New Jersey, 1989.

in numerous reference texts[20, 21] on microwave system design and analysis. For this study, therefore, attenuation due to rain is not considered further.

Paths over Water

Microwave paths over water and certain other highly reflective terrain conditions require design consideration of ground reflections. Under certain conditions these reflected signals can cause a cancellation of the direct signal, resulting in a disruption of communications. For reliability requirements up to about 99.99%, links can be designed with sufficient margin to overcome fades due to reflection. However, for higher reliability requirements, this approach may become impractical. It may be possible to choose sites and antenna heights to provide screening or blocking of all potential reflective signal paths. Where local conditions permit, a so-called high-low technique can also be used to advantage. In this technique, one end of the path is situated on a mountain ridge or very high point, and the other end on a very low point. The difference in heights will place the principal point of reflection at a location where signal cancellation rarely results. This high-low technique is a good solution, where possible, if the operating frequencies are in the 2 or 4 GHz range but use of 6 GHz and above would "render the scheme questionable."[22]

Radio links to off-shore platforms, such as oil drilling are an additional concern. The antennas commonly used at 6 GHz produce a much narrower beam than those used at 2 GHz. The antenna on the off-shore platform must be sufficiently stable to ensure that the beam remains aligned with the shore station. In some cases, the stability of the antenna platform may be sufficient for operation at 2 GHz but not at higher frequencies such as 6 GHz.

Consequently, some over-water paths that were designed at 2 GHz may not operate reliably at 6 GHz without significant re-engineering of the site.

Atmospheric Multipath

Atmospheric multipath is a condition that results when the atmosphere becomes stratified and several distinct signal paths may exist between the transmit and receive antennas. In such a situation there are short intervals when the various signals cancel one another, resulting in rapid but very deep fades. The incidence of multipath fading varies considerably with climatic and terrain conditions. In the most favorable areas, for example paths in dry windy mountainous areas, it may be essentially non-existent.[23] Hot, humid

---

20 GTE Lenkurt, Engineering Considerations for Microwave Communications Systems, GTE Lenkurt Inc., San Carlos, California, 1975, Page 44.

21 NEC America, Inc., Digital Microwave Radio Engineering Fundamentals, Radio and Transmission Division, MSD-3003, Page 6-5.

22 GTE Lenkurt, Page 52.

23 Ibid., page 55.

coastal areas typically have a high incidence of multipath fading, and inland temperate areas are in between these extremes.

The effects of atmospheric multipath have been extensively measured and analyzed. Analysis methods developed by Vigants of Bell Telephone Laboratories[24] have been widely accepted and proven out by many years of practice. Most manufacturers of microwave equipment rely on Vigants' methods to account for multipath in microwave link design. Important factors in the analysis of multipath are the prevailing climate and terrain conditions at the location of the microwave system. Figure 4-3 is a description of these climate/terrain conditions resulting from the Bell Laboratories work. As shown, the conditions vary from ideal in the Rocky Mountain region to very difficult on the Gulf and lower East Coasts.

As described in Appendix D, application of the Vigants' method for atmospheric multipath calculations shows reliability at 2 and 6 GHz is quite comparable even for relatively long paths. For unusually long paths, less measured data is available to substantiate these standard methods. For example, a report of the International Radio Consultative Committee[25] identifies these analysis methods as valid for path lengths up to 100 km. However, little measured data is available for validating the methods for distances greater than about 80 km. For purposes of this study, a more conservative upper limit of 80 km (50 miles) will be used. For path lengths greater than this upper limit, use of 2 GHz may be more advantageous than 6 GHz.

Atmospheric Ducting

Atmospheric ducting may occur when conditions are such that temperature inversions occur in the atmosphere near the ground. The familiar smog-producing temperature inversion is an example of this condition. Under these conditions, the radio signal may become effectively trapped between these layers and result in a much smaller signal reaching the receiver. These conditions may last for many minutes, resulting in unacceptable disruption of communications. One such condition was described by Harris Corp. in response to the FCC Emerging Technologies NPRM[26]. The Harris Corp. reported loss of signal due to atmospheric ducting on a 6 GHz microwave system with a 37 km path length along the South Carolina Coast. A parallel 2 GHz path was reported to be unaffected.

Analysis of these ducting conditions is less standardized than the other reliability factors described earlier. Various methods have been used to define a "trapping frequency," above which, communications may become unreliable. The Harris Corp. analysis and other

---

24 Vigants, A., *Space Diversity Engineering*, Bell System Technical Journal, Vol. 54, No. 1, January 1975.

25 *Recommendations and Reports of the CCIR*, 1986, Volume V, Report 388-5, International Telecommunication Union, Geneva, 1986

26 Harris Corp./Farinon Div., *Comments of Harris Corporation - Farinon Division in the Matter of Redeployment of Spectrum to Encourage Innovation in the Use of New Telecommunications Technologies (ET Docket No. 92-9)*, June 8, 1992.

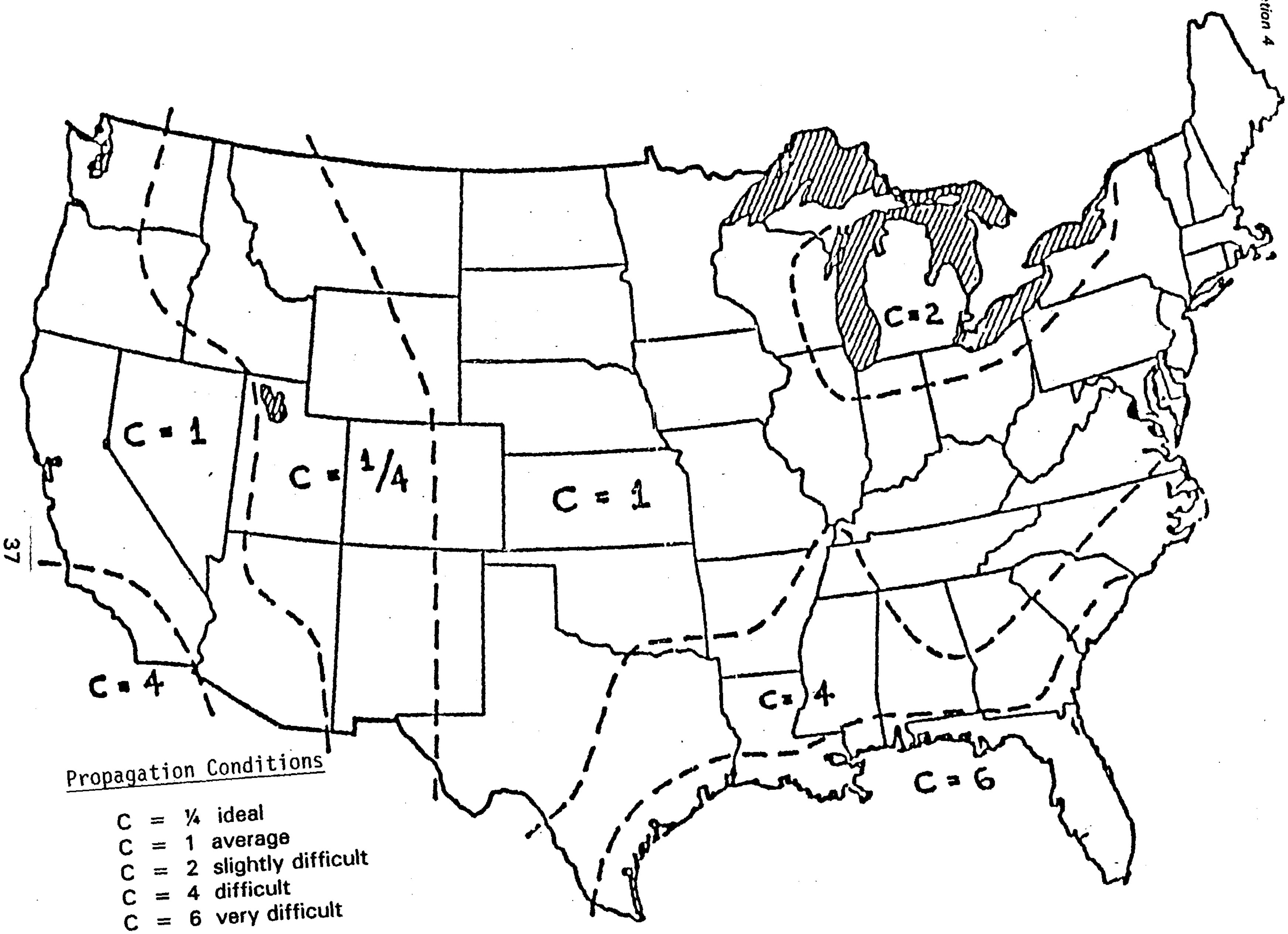

Figure 4-3. Values of Climate-Terrain Factors.

studies[27, 28] suggest that extra height on the antenna to clear the surface duct effect will provide protection against these "blackout" fades. The extra height needed, however, may not be practical in all cases.

While the analysis of ducting effects may be less standardized, it is generally agreed that the same climate/terrain trends remain as in atmospheric multipath, since both are caused by stratified layers in the atmosphere. Atmospheric ducting is virtually non-existent in mountainous areas whereas it has a higher incidence in hot, humid coastal areas. Figure 4-3 again is useful in defining these areas.

In these areas subject to ducting, FCC records indicate that many microwave paths have been successfully designed to operate reliably at both 2 and 6 GHz for both private and common carrier use. Nevertheless, it is agreed by many experts that in these areas, longer microwave paths at 2 GHz tend to be more reliable than at 6 GHz. The minimum path lengths at which these reliability problems may occur has not been well defined. Harris Corp. cited ducting problems along the South Carolina Coast, on a 37 km path, in an area indicated on Figure 4-3 as very difficult propagation conditions. A provisional value of 30 km (19 mi.) is proposed herein as a guideline to identify the path lengths at which reliability problems may occur at 6 GHz in the very difficult propagation areas defined from Figure 4-3. A somewhat larger value of 50 km (31 mi.) is proposed as a guideline in the difficult propagation areas defined in Figure 4-3.

Reliability Summary

The discussion provided here addressed key factors that lead to fading of the microwave signal and the occasional communication disruptions that result. All microwave systems will experience occasional fades. The system designer takes these various factors into account to provide sufficient excess power, or fade margin, to overcome these fades. In most instances, paths can be designed to achieve the required very high reliability at either 2 GHz or 6 GHz.

Because of certain atmospheric conditions known as ducting, unusually long microwave paths may be more difficult to design for high reliability at 6 GHz than at 2 GHz. This critical length is difficult to define but clearly varies with location. For most areas of the United States where propagation conditions are average to ideal, severe ducting rarely occurs. In these cases, reliability at 2 and 6 GHz are very similar out to at least 80 km (50 mi.). On the other extreme are the low-lying coastal areas of the Gulf and Southeastern States, where ducting is more severe and propagation conditions identified as very difficult. As a guideline, a provisional value of 30 km (19 mi.) is proposed herein as the minimum distance at which reliability problems may occur at 6 GHz in the very difficult propagation areas defined from

[27] GTE Lenkurt, Page 52.

[28] Dougherty, H.T. and Dutton, E.J., *The Role of Elevated Ducting For Radio Services and Interference Fields*, NTIA Report 81-69, National Telecommunications and Information Administration, March 1981.

Figure 4-3. A somewhat larger value of 50 km (31 mi.) is proposed in the difficult propagation areas defined in Figure 4-3.

The distances identified here can serve as guidelines for identifying which of the 2 GHz non-government fixed systems may be candidates for potential accommodation in the 1710-1850 MHz band. To precisely determine the number of links that would exceed these path length guidelines would require a link-by-link examination. Moreover, even for these links that do satisfy the guidelines, relocation may not be necessary if new technologies and the incumbent users can share spectrum without interference. This is likely to be the case for many links that are not in or near major metropolitan areas. Furthermore, only a portion of the links identified by these guidelines will likely require the highest level of reliability requirements where operation at 6 GHz may be a problem. Based on a preliminary examination, it is estimated that up to 2% of the nearly 30,000 links may have difficulty operating reliably in higher frequency bands. However, each case should be addressed on its own merit, and path lengths less than these distances could also be considered upon adequate showing of need.

SECTION 5
FINDINGS

INTRODUCTION

As a result of the FCC proposed rule making on emerging technologies, many of the incumbent 2 GHz non-government fixed microwave users suggested that the spectrum under consideration by the FCC should be broadened to other bands, including Federal spectrum. This study addresses the potential availability of the 1710-1850 MHz band to accommodate 2 GHz non-government microwave systems that might be displaced as a result of the proposed FCC action.

SPECTRUM USAGE

The 2 GHz non-government fixed service bands addressed in this study are used almost exclusively by conventional point-to-point fixed microwave systems. The equipment used is typically off-the-shelf commercially available systems. These systems serve a variety of private and common carrier functions, including feeder links for cellular sites, generation and distribution of oil, gas, and electrical power, railroad monitoring and control, and local government communications. They require very high communication reliability and operate over paths of 1 to over 160 km in length. As shown in Figure 2-1, the nearly 30,000 fixed links in these bands are widely used throughout the United States. While the densest use is in or near urban areas, many of the links are located in rural areas.

The Federal Government band addressed in this study is the 1710-1850 MHz band. A wide variety of Federal systems are operated in this band including conventional fixed microwave, high power satellite control transmitters, air and land military combat training systems, airborne video transmitters, civil disaster response systems, and public safety systems. Many of these equipments are for specialized applications. The airborne activities have a particularly large effect on overall spectrum use because of their wide geographic impact. Continued flexibility is necessary for using such Federal radiocommunications in this band.

RELOCATION OF NON-GOVERNMENT FIXED

The analysis shows that due to the present use of the 1710-1850 MHz band and the need to maintain flexible, continued use by Federal agencies, this band could not accommodate all or even most of the existing 2 GHz private-sector fixed microwave links.

In most parts of the United States, it is feasible to accommodate a limited number of 2 GHz non-government fixed links into the 1710-1850 MHz band. As shown in TABLE 4-1, in most of the 50 top metropolitan statistical areas, capacity is available in the 1710-1850 MHz band to support a limited number of additional fixed links. Figure 4-2 provides a national overview of spectrum availability in the 1710-1850 MHz band.

Locations in the United States where it will be difficult to accommodate non-government fixed links into the 1710-1850 MHz band include areas near: 1) the major military electronic and missile test ranges located in the Southwestern States and Florida, shown in Figure 3-4; 2) major military training and exercise areas; 3) cities adjacent to the Canadian border; and 4) Air Force Satellite Control Facilities. Southern California will be an especially difficult area to accommodate additional non-government links.

The basis for accommodating non-government fixed systems into the band should include documentation of the inability to operate reliably at higher frequencies, the inability to continue to operate at 2 GHz without causing interference to new systems, and the ability to share compatibly with existing Federal systems. Final determination should be based on the specifics of the case and analyzed relative to reliability and interference protection of existing Federal systems. The FCC and NTIA should jointly develop a specific process to identify the candidate non-government systems and to grant frequency assignments in keeping with current rules and regulations.

RELIABILITY

The relocation of 2 GHz non-government fixed systems to higher frequency bands, such as 6 GHz, raises the question of communications reliability. The issues involved are complex and not easily resolved. The analysis presented herein supports the view that for most geographic areas, fixed links at 6 GHz can be engineered to be at least as reliable as those at 2 GHz. However, users of microwave systems have reported instances of reliability problems at 6 GHz. The objective of this study was not to develop a conclusive answer to this question. It was found useful, however, to summarize the reliability issues where there is general agreement among microwave design experts and users.

a. Reliability difficulties due to signal attenuation from rain is not an issue at either 2 or 6 GHz. Rain attenuation only becomes a significant design factor at frequencies above about 10 GHz.

b. Designing fixed microwave systems to achieve high reliability requires consideration of various climate and terrain factors. Identification and analysis of these various factors have been well documented in the technical literature and have received wide acceptance. Figure 4-3 provides a widely accepted description of the various climate and terrain factors for the United States.

c. Most parts of the United States are characterized as having average or better than average climate/terrain propagation conditions. In these areas, straightforward engineering design can achieve highly reliable communications in both the 2 and 6 GHz bands. This is evident from both a review of technical factors as well as the extensive use of fixed microwave systems in both bands. In these areas, the major issues in relocating existing 2 GHz fixed links to 6 GHz are the additional cost to upgrade equipment and possible strengthening of antenna towers. In few cases will construction of additional relay towers be required, even for relatively long paths.

d. Relatively small portions of the country are recognized as having difficult or very difficult climate/terrain propagation conditions. These include the low-lying coastal areas in Southern California, the Gulf, and the Southeastern Coasts. In all of these areas, fixed microwave systems at both 2 and 6 GHz have been engineered to provide highly reliable communications. Nevertheless, design of microwave systems at 6 GHz in these areas may entail additional cost and design limitations compared to 2 GHz. Conversion of existing 2 GHz microwave systems to 6 GHz may require additional relay towers. In the most difficult coastal areas, relocation of even modest length paths may require special consideration.

The 1710-1850 MHz band can effectively serve as an alternative for relocating 2 GHz non-government fixed systems that for technical reasons cannot operate reliably at higher frequencies, such as 6 GHz. Guidelines for identifying which links should be candidates for accommodation into the 1710-1850 MHz band may be based on path length using the climate/terrain areas defined in Figure 4-3 as follows:

CLIMATE/TERRAIN	LENGTH
Average or better	80 km (50 miles)
Difficult	50 km (31 miles)
Very difficult	30 km (19 miles)
Over water	All

These guidelines can serve as a first step in identifying candidate non-government fixed systems to consider for relocating into the 1710-1850 MHz band. It is estimated that up to 2% of the nearly 30,000 operating at 2 GHz links may have difficulty operating reliably at higher frequencies. However, each case should be addressed on its own merit, and path lengths less than these distances should also be considered upon adequate showing of need.